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THE OUTERMOST BELT OF CHARGED PARTICLES

by

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SUMMARY

This report deals with the result of the study of a zone of charged particles with comparatively low energies (from ~100 ev to 10 — 40 kev), situated beyond the outer radiation belt (including the new data obtained on Electron-2 and Zond-2).

The authors review, first of all, and in chronological order, the space probes on which data on soft electrons and protons were obtained beyond the radiation belts. A brief review is given of some examples of registration of soft electrons at high geomagnetic latitudes by Mars-1 and Electron-2. It is shown that here, as in other space probes, the zones of soft electron fluxes are partly overlapping with the zones of trapped radiation.

The spatial distribution of fluxes of soft electrons is studied in light of data obtained from various space probes, such as Lunik-1, Explorer-12, Explorer-18, for the daytime region along the magnetosphere boundary from the sunny side. The night region of fluxes is examined from data provided by Lunik-2, Explorer-12, Zond-2, and the results of various latest works with regard to the relationship of that distribution with the structure of the magnetic field are examined and compared. The essentially new revelation of the magneto—neutral layer on the night side is discussed.

The temporal variations according to data from Electron-2 are discussed.

Finally the authors make brief remarks as to the origin of soft electrons and in conclusion they emphasize the importance of the outermost zone of charged particles from the geophysical standpoint. A further study is recommended, particularly of the part of the outermost zone where the daytime and nighttime parts apparently join near the neutral points on the daytime side and in the magneto-neutral layer of the night part of the zone.

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The results of the study of the zone of charged particles beyond the outer radiation belt and whose energies are comparatively low (from ~ 100 ev to 10 – 40 kev), are considered in the present work. The study includes more particularly the new data contributed by observation aboard the satellite Electron-2 and the space rocket Zond-2.

As is well known, the Earth's radiation belts were discovered in 1958 during experiments for the study of cosmic rays. In these experiments the apparatus used was naturally appropriate for the registration of particles with comparatively low energies, beginning from tens of kev, and that is why the impression was conveyed at the outset that conditions, characteristic of interplanetary space, must take place beyond the boundary of the zones of trapped radiation.

Experiments with charged particle traps on Soviet lunar rockets [1] have revealed that a zone of electron accumulation exists beyond the outer radiation belt near the geomagnetic equator. In this zone, the concentrations and the fluxes exceed considerably those known to exist in the outer radiation belt. According to the data of Luna-2, the extension of this zone is of the order of 40 000 km. The appearance of intense low-energy particle fluxes ($\sim 10^8 \text{ cm}^{-2} \cdot \text{sec}^{-1}$) beyond the outer radiation belt was interpreted as being the result of solar plasma fluxes' interaction with the peripheral regions of the Earth's magnetic field [2]. The mechanism indicated in [3] was considered as one of the possible thermalization processes of solar plasma. Subsequently, other various acceleration mechanisms of solar plasma electrons were also considered [4, 5]; however, the basic idea of emergence of the outermost radiation belt, visualized as a result of certain boundary effects of solar plasma fluxes' interaction with the Earth's magnetic field fully kept its significance.

Although more than five years have elapsed since the detection of this zone by Soviet lunar rockets, a significant part of the works devoted to it appeared only after 1962, so that the terminology, referring to it, is still unsettled. At the outset is was called the "third radiation belt" [6, 7]. Then, in 1961 it was proposed [8], in order to underline the distinction of the physical properties of this zone from the radiation belts, to call this intermediate zone of existence of low-energy charged particles, situated between the zone of trapped radiation and the unperturbed solar wind, the outermost belt of charged particles (see also [9, 10], or, later on, the outermost zone of charged particles [11]. Other denominations, and in particular the one proposed in [12] for fluxes of soft charged particles beyond the boundary of trapped radiation [12], namely " auroral radiation", appear to us less fortunate.

1. - EXPERIMENTAL DATA

Table 1 shows in chronological order (according to launching data) the space probes on which were obtained data on soft electron and proton fluxes beyond the radiation belts, alongside with the method of their observations and the values of the angle λ_{3C} (see further the Fig. 7), corresponding to the moments of observations.

The orbits of most of the space probes enumerated in the table, passed near the ecliptic plane. To the number of devices on which fluxes of electrons with energies $E_e > 100$ ev were observed beyond the boundary of trapped radiation at high latitudes (and more remote from Earth), so far refer only to Mars-1 and Electron-2.

2. - OBSERVATIONS AT LOW LATITUDES

Because of the lack of space we shall limit ourselves here to a brief review of some characteristic examples of registration of soft electron fluxes.

The registrations of the collector currents of the integral type of charged particle traps, installed aboard the space rocket Luna-2, launched at the night side, are plotted in Fig. 1 . Plotted in the same figure are the data of counter indications of higher-energy particles, installed on the rocket [20]. As may be seen from the diagram, the zone of intensive fluxes of soft electrons are in the considered case, entirely beyond the zone of registration of energetic particles. During experiments aboard Luna-1, fired on the daylight side, these zones noticeably overlapped.

It should be noted that the trajectory of Luna-2 passed near the geomagnetic equator and crossed it near $\sim 8.5\ R_E$.

TABLE 1

Space Probe	Launching Date	Reference	λ_{3C} *	Method of measurements
LUNA-1	1 Jan.1959	[6]	285	Integral Trap (Electrons with energy $E_e > 200$ ev
LUNA-2	12 Sep.1959	[1]	135	Same
EXPLORER-12	16 Sep.1961	[13] [14]	285-360 & 225	Integral Detector CdS ($E_c > 200 - 500$ ev)
MARS-1	1 Nov.1962	[15]	200	Integral Trap ($E_e > 100$ ev)
EXPLORER-18	27 Nov.1963	[16]		Same
		[17]	270-360	Modulation trap (ions $E_i \sim$ kev, electrons 65 — 210 ev)
ELECTRON-2	30 Jan.1964	[18]		Electrostatic analyzer (Ions $E_i \sim$ kev)
		—	290 & 210	Integral trap (electrons with $E_e > 100$ ev)
		[19]		Electrostatic analyzer (ions and electrons with $E \sim 100$ ev — 10 kev)
ZOND-2	30 Nov.1964	[11]	230	Integral Trap (electrons with $E_e > 70$ ev)

* λ_{3C} is the angle between the directions Earth-Sun and Earth-AES **

** the original denotation being maintained throughout.

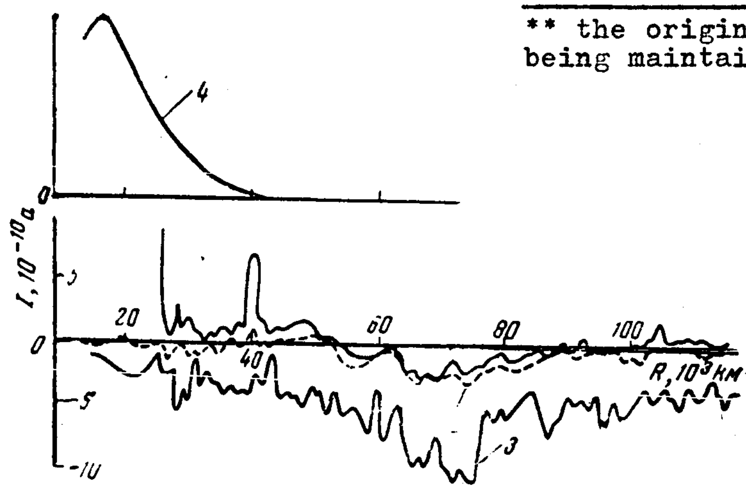

Fig. 1. - Collector currents of integral charged particle traps [1] and counting rate of hard radiation [20]

1 — upper limit of collector currents in traps with damping grid $\varphi = -10, -5$ and 0 v; 2 — lower limit of the same currents; 3 — upper limit of currents in the trap with $\varphi = 15$ v; 4 — counting rate in relative units.

The intensity course of electron fluxes registered at the daytime side with the aid of integral trap installed aboard Explorer-18 is shown in Fig. 2 [16]. As in the case of Luna-2 the electron fluxes were observed on both sides of the boundary of trapped radiation (on the daylight side near the geomagnetic equator the latter coincides with the boundary of the magnetosphere). Owing to the fact that the orbit apogee of Explorer-18 lay at great distances from Earth, the outer boundary of the zone of thermalized solar plasma was also registered on it; this boundary is identified with the shock wave front.

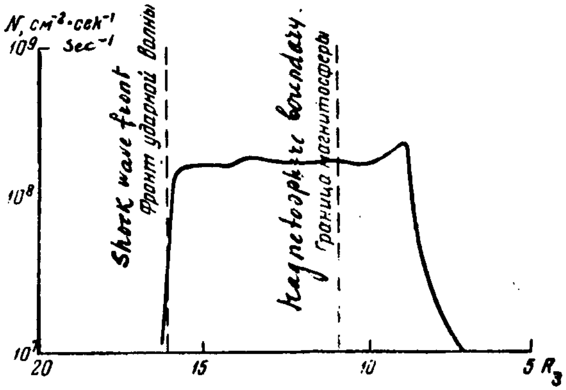

Fig. 2. - Electron fluxes with $E_e > 100$ ev according to data of the integral trap installed aboard Explorer-18 [16]

Proton fluxes were registered in the entire transitional region beyond the magnetosphere boundary with the aid of a modulation trap [17] (they were also measured with the help of the electrostatic analyzer with energies to ~5 kev together with the omnidirectional fluxes of electrons in the 65 — 210 ev range [17]). In the transitional region, the intensity of fluxes of protons, originating from the side of the Sun exceeded by about a factor of 2 the intensity of the fluxes from opposite direction.

Data obtained on Explorer-12 at intersection by the probe of the magnetosphere boundary from the subsolar side on 13 November 1961 are plotted in the Fig. 3 [next page] [13]. Inside the magnetosphere, near the boundary, a small maximum was observed in the readings of CdS total energy detector, and also an intensity maximum of electron fluxes with energies from 40 to 50 kev. Immediately beyond the magnetosphere boundary (determined by the magnetic field jump and the beginning after it of the turbulent field region), a sharp increase was observed in the flux of energy registered by the CdS crystal, up to ~50 erg·cm^{-2}·sec^{-1}. An indirect estimate of the magnitude of the electron flux and energy gave respectively 10^{10} cm^{-2} sec^{-1} and 2.5 kev. The measurements were completed in time of a magnetic storm, and are therefore not typical of undisturbed periods. All other cases of observation of electron fluxes beyond the magnetosphere boundary were analyzed in [14]. After every fortunate crossing of the magnetosphere boundary (the CdS crystal was not lit up by the Earth - reflected solar radiation) electrons were observed whose fluxes exceeded the limit value of ~ 1 erg cm^{-2} sec^{-1} (the region where such fluxes were registered is shown in Fig. 8).

The fluxes of electrons with energies $\sim 0.5 - 40$ kev [14] were registered again with the aid of the same total energy detector on the night side. A more precise estimate of energy could not be made. Discrepancies exist as regards the estimate of electron fluxes. In [10] the value of the flux is estimated as being $\sim 10^{8} - 10^{9}$ cm^{-2} sec^{-1}, whereas in [14] the value of 10^{12} cm^{-2}$\cdot$sec^{-1} is brought up. No direct joining of the night and daytime regions of electron fluxes were revealed from the data obtained on Explorer-12 [13, 14].

The trajectory of the cosmic rocket Zond -2 passed above the night side of the Earth at about the same region, where the night region of fluxes was observed on Explorer-12. The course of the constant component of the collector current of the modulation trap installed on the satellite, up to the geocentrical distance of ~ 7.3 R_E, is shown in Fig. 4. The first session of measurements was discontinued at that point [11]. The proton fluxes on that portion of the trajectory were not registered with the help of the modulation part of the circuit. By the end of measurement session the flux of electrons reached the substantial value of $\sim 3 \cdot 10^{8}$ cm^{-2}sec^{-1}.

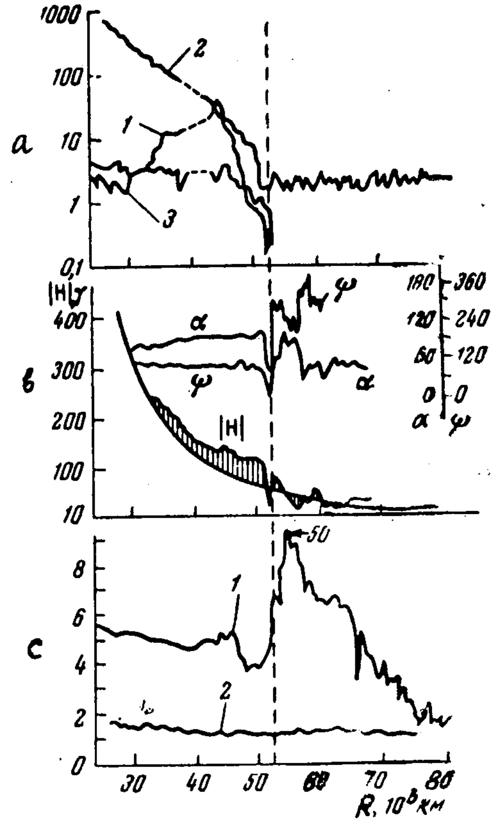

Fig. 3. - Readings of the devices on Explorer-12 at crossing the boundary of the magnetosphere on 13 November 1961 [13]

a — hard radiation counter: 1 — $40 < E_e < 50$ kev, $E_p > 20$ Mev, 2 - $E_e > 16$ Mev, 3 — $80 < E_e < 100$ kev; b — magnetometer readings; α — angle between H and the direction of satellite's rotation axis; ψ - angle between planes, one of which containing H and the satellite's rotation axis, and the second containing the axis of rotation and the line Sun — satellite; c - readings of the CdS total energy detector readings — 1; background — 2.

3.- OBSERVATIONS AT HIGH GEOMAGNETIC LATITUDES

As already mentioned, so far only Mars-1 and Electron-2 belong to the number of space probes on which intense fluxes of low-energy electrons ($E_e \gg 100$ ev) were observed at high latitudes.

The trajectories of the interplanetary station Mars-1 passed above the night side of the Earth near the meridional plane passing through the line Earth-Sun. The registrations of collector currents of two integral traps of this station are plotted in Fig. 5 after the work [15]. The curve 3 of Fig. 5 describes the counting rate variation of more energetic particles [21]. Comparison of the curves 1 and 2 shows that intersection of the peripheral region of the ionosphere with the outermost zone of charged particles was observed in this case. It should be noted that the zone of soft electron fluxes lies between the lines of force of the geomagnetic dipole corresponding to the $\sim 63 - 73^o$ geomagnetic latitude interval (Fig. 6), in which the zone of maximum aurora reccurrence is situated.

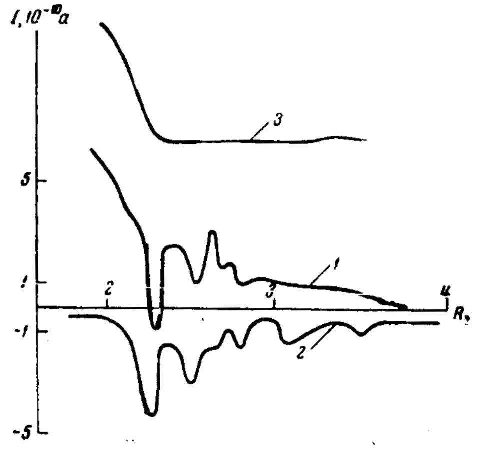

Fig. 5. - Collector currents of integral charged particle traps and counting rate of hard radiation on the Mars-1 probe [15, 21]
1- damping grid potential $\varphi = 0$; 2 - $\varphi = 50$ v ; 3 - counting rate in rel. u.

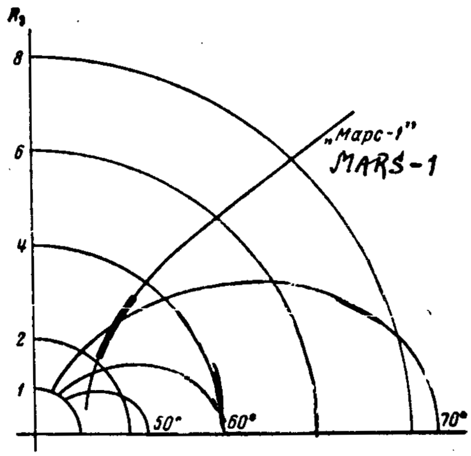

Fig. 6. - Disposition of Mars-1 trajectory relative to the lines of force of an ideal geomagnetic dipole.
The curve's heavy portion denotes the registration region of soft electrons [15].

Electron-2 was the first satellite on which the investigations of low-energy charged particles were conducted systematically and for a prolonged time at great distances from Earth and at high latitudes.

Electron fluxes were registered with the help of satellite-borne electrostatic analyzer [19] and an integral trap of charged particles [22]. When comparing the data obtained, one should bear in mind that primary data (collector current) are brought up for the trap, whereas for the analyzer the data consist of magnitudes of registered fluxes, that is the value of the photocurrent in the collector circuit has already been accounted for. Attention is drawn to the quite satisfactory qualitative agreement between the data obtained with the aid of two different devices. According to the data of the electrostatic analyzer, intensive fluxes of electrons with energies to 10 kev were systematically observed outside the regiom of trapped radiation ($L > \sim 7.5$) [19]. It should be noted that according to data of the integral trap, electron fluxes were not always observed. Let us recall that the collectro current of the trap aboard Electron-2 was determined by the difference of the fluxes, hitting the collectro, with energy exceeding the value determined by the satellite's potential and of the electrons with energy $E_e > 100$ ev. The minimum value of the collector current that could be registered corresponded to a flux $3 \cdot 10^7$ cm^{-2} sec^{-1} (for more details on the subject, see [22]). The results of measurements attest of notable instability of the outermost belt of charged particles, which is in agreement with the instability of the soft electron component of the outer radiation belt [22]. As in the experiments with other space probes, the zones of soft electron fluxes are partly overlapped by the zones of trapped radiation.

4.- SPATIAL DISTRIBUTION OF FLUXES OF SOFT ELECTRONS

Figures 7a and 7б show the spatial distribution of the soft electrons and protons observed at great distances from Earth on various space probes (respectively in the projection on the ecliptic plane and on the meridional plane perpendicular to it); the axis $X_{cэ}$ is directed at the Sun; applied here is the so-called solar-ecliptic system of coordinates.

Near the ecliptic plane (Fig. 7 a) the portions of trajectories on which were registered the fluxes of soft charged particles, form two regions — the daytime and the nighttime ones.

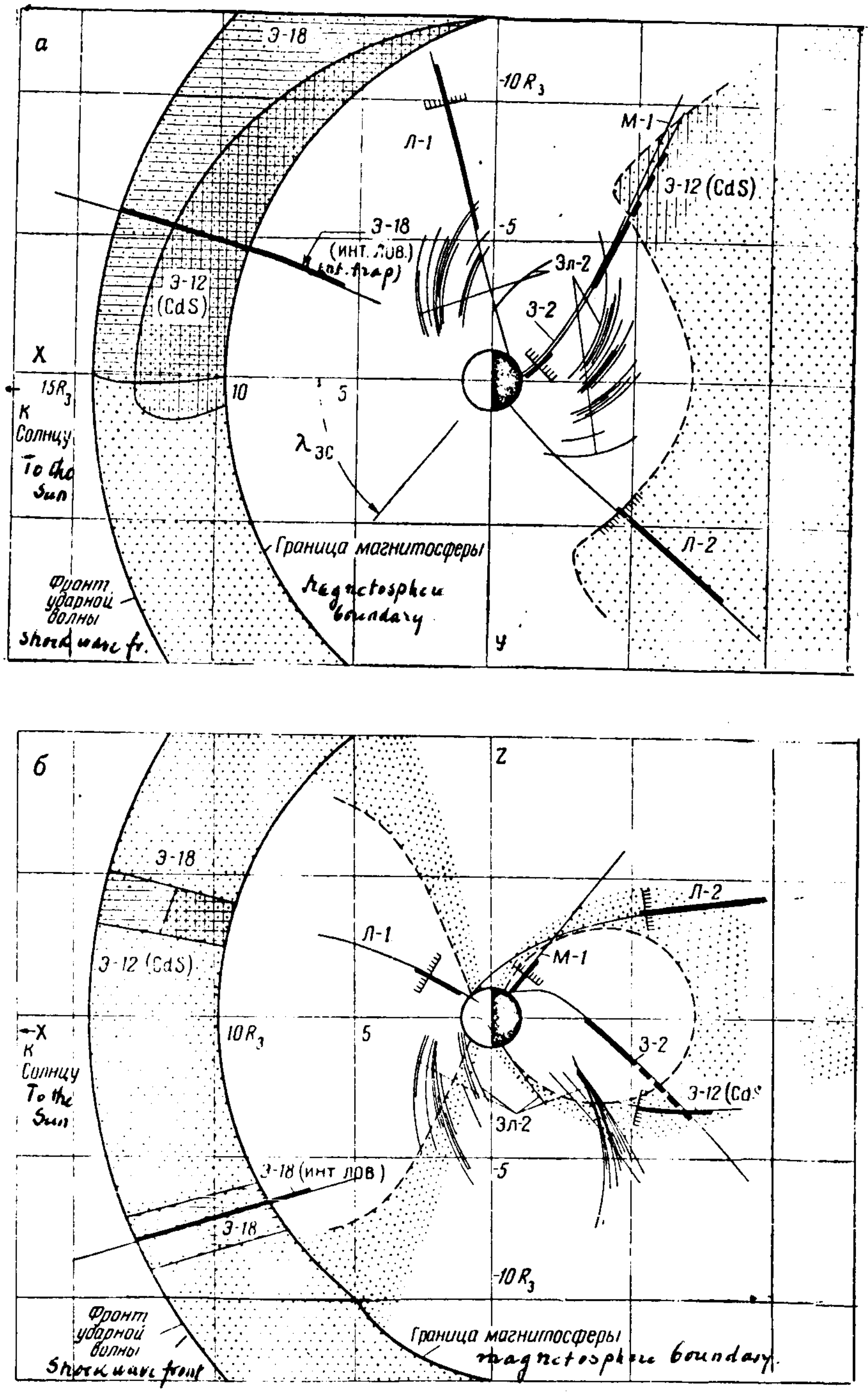

Fig. 7. - Distribution of charged particles as observed on different space probes in the projection on the ecliptic plane (a) and on the meridional plane (б), in the solar-ecliptical system of coordinates.

The portions of trajectories over which the fluxes were registered are shown in heavy lines and shading, while for Electron-2 only those trajectory segments are shown, where fluxes were registered by means of of the integral trap. The approximate boundaries of trapped radiation (dashes and comb-shaped sign) are plotted [20, 21, 23 — 26] with the use of magnetosphere boundary according to [17, 27, 28]. The assumed position of the outermost zone of charged particles is shown by dots.

[Explanation of Russian signs : Л - 1 Luna-1; Л -2 Luna-2; Э stands for "Explorer" , Эл — for Electron; З - 2 stands for Zond and З for Earth.

1.- The daytime region is disposed along the magnetosphere boundary on the side of the Sun. The outer boundary of the region coincides with the shock wave front beyond which are disposed the unperturbed fluxes of solar plasma (Luna-1, Explorer-12, Explorer-18). According to the data of integral charged particle trap, the fluxes of electrons are registered on both sides of the magnetosphere boundary. However, the energy spectrum of soft electrons is more energetic inside the magnetosphere than outside it.

2.- The night region of fluxes (Luna-2, Explorer-12, Zond-2) does not join with the daytime one if one judges this from observations near the ecliptic plane. According to data from Explorer-12, there exists within the break between the nighttime and daytime regions on the morning side, a zone of fluxes of trapped electrons with energy $E \sim 40$ kev, apparently constituting the extension of the outer radiation belt [26]. Whether such break exists also on the evening side is not quite clear. The boundary of the region of trapped radiation in Fig. 8 a is traced symmetrically relative to the axis OX.

The results of high-latitude measurements on Mars-1 and Electron-2 (Fig. 7б) provide basis to assume that the night and daytime regions are interconnected through the high-latitude regions, and therefore, the outermost most belt of charged particles constitutes a single formation of quite complex configuration. The subdivision of the soft electron fluxes registered on Electron-2 into two regions* is apparently imaginary and linked with the seasonal intensity variations of electron fluxes (see # 6).

In reality, up to the present no cases are known, whereby any of the space probes, launched in any direction, on which there were electron indicators with energies of the order of hundreds ev and units of kev, had crossed the boundary of the outer radiation belt without detecting beyond it fluxes of soft electrons. Since the outer boundary of the trapped radiation zone is closed, the assumption should follow that the zone of existence of soft electron fluxes, situated beyond it, also constitutes a single entity. This, however, does not imply that plasma fluxes have identical physical properties and similar origin in either, the daytime or nighttime regions.

* [night and morning]

The region of soft electron fluxes on the night side is situated nearer the Earth than that on the daytime side; this agrees well with the disposition of the boundary of trapped radiation [24, 25, 29]. The night side region of fluxes, detected by Luna-2 and Explorer-12, are disposed symmetrically relative to the line Sun - Earth. There is a certain discrepancy between the data obtained on Luna-2 and Explorer-12 in the estimate of the value of the fluxes: $2 \cdot 10^8 cm^{-2} sec^{-1}$ on Luna-2 [1] and $10^8 - 10^9 cm^{-2} sec^{-1}$ on Explorer-12 [10], in spite of the fact that the trap on Luna-2 was provided with a notably greater viewing angle. No observations in the intermediate midnight region were conducted as yet. Nor has the zone of thermalized plasma been yet observed in high latitude regions, for to-date, no satellites or rockets have been launched that would cross the magnetosphere boundary at high latitudes.

5. - RELATIONSHIP BETWEEN THE SPATIAL DISTRIBUTION OF SOFT ELECTRON FLUXES AND THE STRUCTURE OF THE MAGNETIC FIELD

The link between the daytime and nighttime regions of the zone of soft electron fluxes probably depends on the structure of the Earth's magnetic field at greater distances from the Earth and, more particularly on that of the night side and in the magnetosphere tail. The character of the relationship between these regions may in particular be entirely different depending upon whether or not the magnetosphere is in the antisolar direction or is closed.

In the question of the magnetosphere shape on the night side, various authors adhere to different viewpoints [30 - 38]. Experimental data for the solution of this important problem are still scarce. However, measurements of the magnetic field on Explorer-14 [39] and on Explorer-18 [40] constituted strong arguments in favor of the open model of the magnetosphere. In January 1964 Explorer-14 was on the night side of the Earth (the angle between the directions Earth-satellite and Earth-Sun constituted $\sim 140 - 150°$). As the object drifted farther away from Earth and beginning with $\sim 9 - 10 R_E$, the field lost its dipole character and remained constant in direction and strength ($H \sim 30 - 50 \gamma$) through orbit apogee ($\sim 15 R_E$). In this region the field was directed toward the side from the Earth and away from the Sun, that is, the behavior of the field was precisely of the nature required in the open model or at least in the magnetosphere — strongly extended in the antisolar direction. It should be noted that the data brought out in [39] still have a preliminary character; however, they agree well with both, the earlier conducted magnetic measurements on Explorer-10 [41] and the subsequent data from magnetic measurements on Explorer-18 [40]. The latter, considerably exceeding in volume those obtained in [39, 41], confirm that on the night side, beyond the limits of 8 — 10 R_E, the magnetic field loses entirely its dipole character, the magnetic lines of force expand and run practically parallelwise (Fig. 8).

Essentially new is in [40] the revelation of the magneto-neutral layer on the night side. Cases of change by 180° in the direction of the magnetic field were observed more than once near the geomagnetic equator plane, and in the narrow layer ($\sim$ 600 km) it was near zero. Measurements were conducted through $\sim 31 R_E$ and the magnetic field in the magnetosphere tail constituted then 10 — 15 γ.

The system of currents assuring the structure of the field in the "tail" part of the magnetosphere open in the antisolar direction, is schematically shown in Fig. 9 borrowed from [32]. In order that the field structure, observed in the experiments [40] may be materialized, it is necessary to assume the existence of sufficiently dense plasma in the magneto-neutral layer. Starting from the necessity of existence of static equilibrium in the transverse section of the night part of the magnetosphere, and taking into account the characteristics of electron fluxes registered on various space probes, the conclusion is made in [38] that the fluxes of soft electrons observed near the geomagnetic equator on Luna-2 and Explorer-12, are precisely situated in the magneto-neutral layer. One should bear in mind that in essence, it is estimated in [38] that all the energy of the observed electrons goes to creating plasma pressure in a direction parallel to the magnetic field; the accounting of electron motion in a direction parallel to the magnetic field must increase the estimates of the required electrons brought out in [38]. It is possible that the gegenschein phenomenon is linked with the existence of that layer [38, 42, 43].

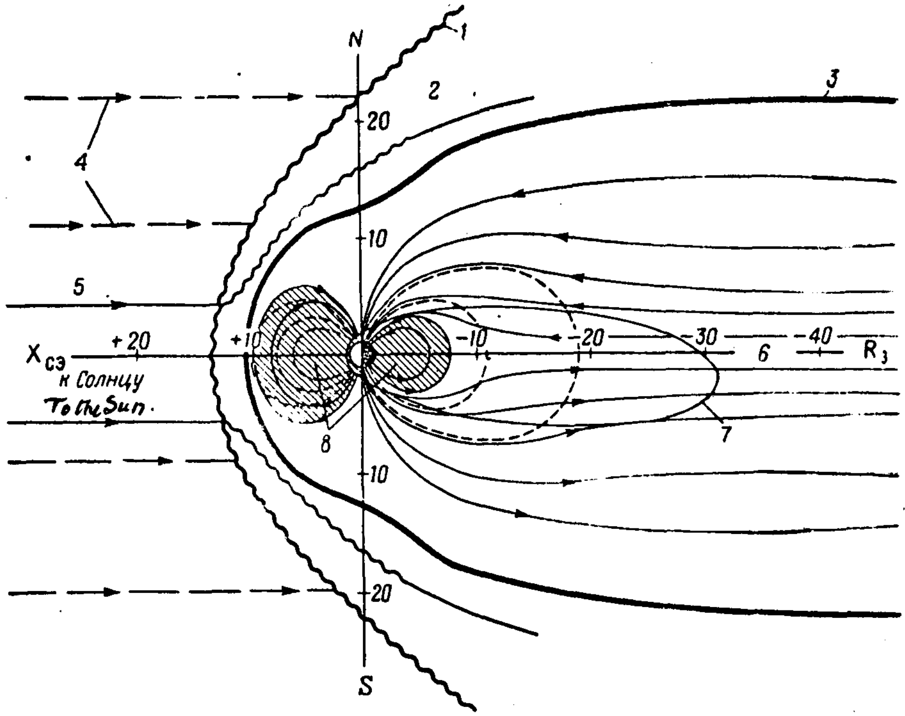

Fig. 8. - Structure of the Magnetic Field in the tail of the magnetosphere according to measurements on Explorer-18 [40]

1 — shock wave front; 2 — turbulent region; 3 — magnetosphere boundary; 4 — solar wind; 6 — neutral layer; 7 — 41st orbit of Explorer-18; 8 - lines of force of the manetic field after theoretical calculations (dashes) and according to experimental data (solid lines). Shadings point to regions occupied by the radiation belts.

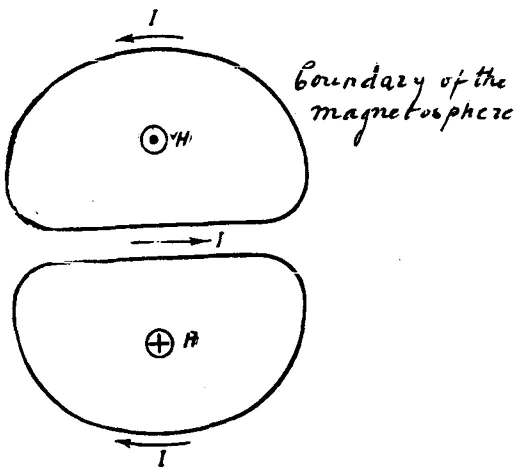

Fig. 9.- System of currents in the magnetosphere tail according to [32]

If the magnetosphere is open in the antisolar direction, all the lines of force originating from polar regions, move in two parallel beams, between which the magneto-neutral layer is located, in the antisolar direction and to infinity, while enveloping the zone of trapped radiation. The lines of force running along the surface of these beams and washed by the solar wind, flying past the magnetosphere, form on the Earth's surface two rings (around the North and South poles) along the high-latitude boundaries of the zones of trapped radiation (it is natural that the trapped radiation can be disposed only on closed lines of force). These rings correspond about to the zones of maximum aurora recurrence. The energetic electrons forming on the magnetosphere boundary and in the magneto-neutral layer at solar wind interaction with the geomagnetic field may apparently penetrate along these lines of force into the depth of the magnetosphere through to aurora zones. From this point of view, just as in agreement with the earlier expounded ideas [12], the regions of soft electron fluxes detected on the night and daytime side of the Earth constitute a single formation of complex configuration, apparently closely linked with the aurora zones.

If the magnetosphere is closed, there remains, as formerly, the possibility of direct penetration of thermalized solar plasma in the region of neutral points situated at magnetosphere boundary on the daytime side of the Earth (see, for example, [44 - 46]. Their position depends evidently on the character of solar plasma fluxes' interaction with the geomagnetic field and on the structure of the interplanetary field.

The possibility of plasma breakthrough at neutral points, with subsequent drift of leaked charged particles across the lines of force of the magnetic field, bringing these particles to the night side of the magnetosphere, is considered in [46].

The results of measurements on AES Electron-2, expounded in #6, the satellite crossing at the initial stage of its flight over morning portions of the orbit, the lines of force of the magnetic field near the southern neutral point, speak apparently in favor of representations developed in [46].

Other explanations can apparently be proposed for the origin of the zone of soft electron fluxes on the night side of the Earth, for example, within the framework of magnetosphere models [31, 33, 37], in which fairly low-energy particles effect in the outer part of the magnetosphere complex convective motions, However, the structure of the magnetic field on the night side, adopted in these works, does not apparently correspond to the data of direct observations.

Moreover, it should probably be taken into account that there may arise a possibility of appearance of soft electrons as a result of some local mechanisms of charged particle acceleration in the peripheral regions of the Earth's ionosphere, usually considered in connection with the origin of the outer radiation belt [47, 48].

6. - TEMPORAL VARIATIONS AFTER THE DATA OF ELECTRON-2

The observations of soft electron fluxes with the aid of the three-electrode integral charged particle trap on AES Electron-2 allow a preliminary conclusion on the presence of relatio ship among the observed fluxes of soft electrons, the orientation of the axis of the Earth's magnetic dipole relative to the direction at the Sun and the geomagnetic activity.

We presented in Fig. 10 the time variations of K_p- indices over the initial stage of flight of the satellite (which, according to [49] and [11], correlate with the velocity and intensity of solar plasma fluxes). The geocentrical distances are indicated, on which the fluxes of soft electrons were registered on night (δ) and morning (ϵ) segments of the orbits of Electron-2, and also the angle φ, close to the value of the geomagnetic latitude of the subsolar point of the magnetosphere *. When examining this drawing one should bear in mind that we do not dispose of uninterrupted data on the magnitude of the collector currents of the trap;the time intervals, corresponding to the presence of information, are shown in Fig. 10, in the form of heavy portions of the line. Let us remember again, that aside from fluxes of electrons positive ions may also penetrate into the trap, as a consequence of which the registered negative collector currents will allow to estimate only the lower limits if the values of electron fluxes.

From the data brought up it may be seen that fluxes of soft electrons were registered over morning orbits of the satellite, and mostly at the time when the southern magnetic pole had maximum inclination toward the side of

*[see infrapaginal note p. 16]

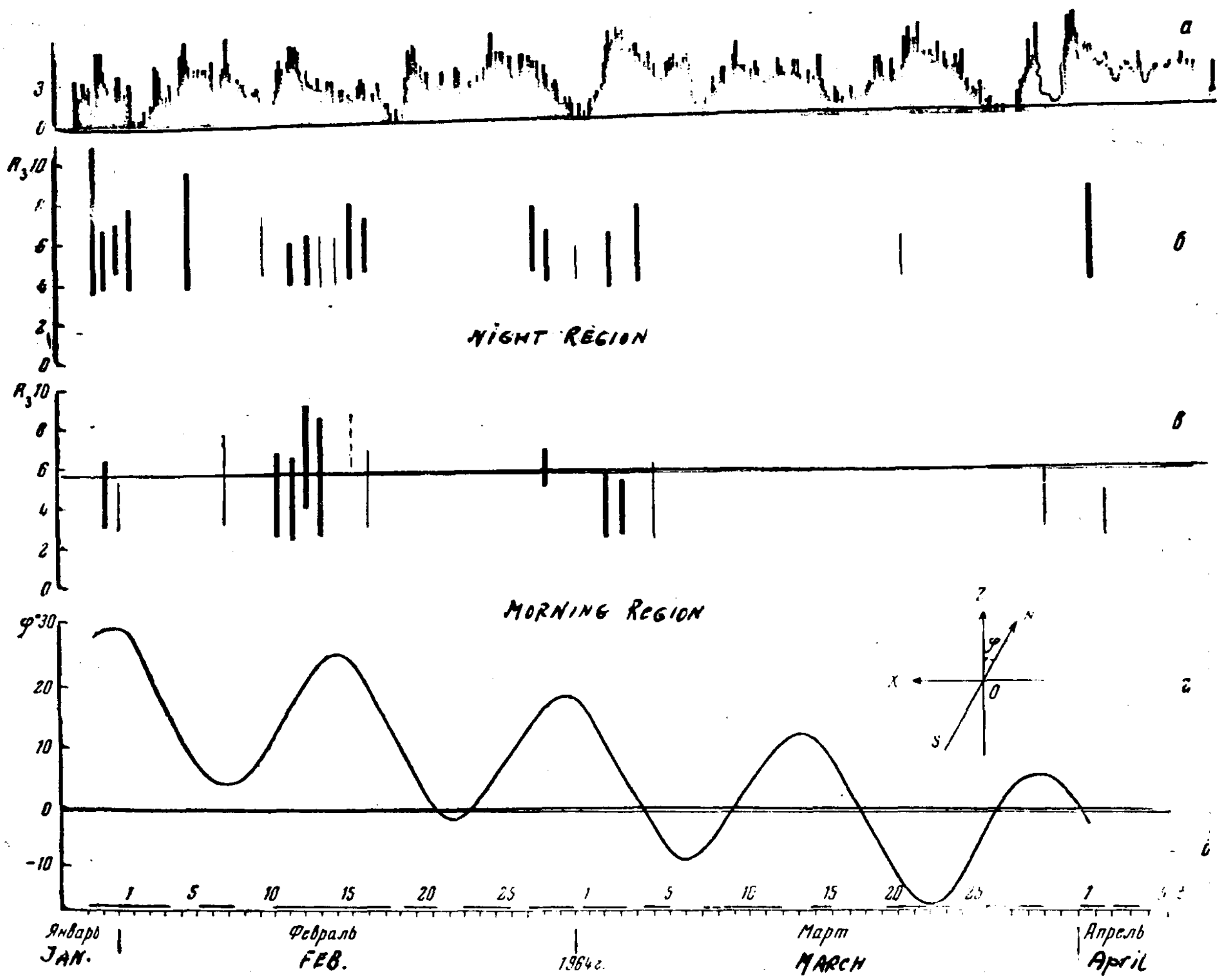

Fig. 10 - Comparison of the cases of registration of soft electron fluxes after the data of Electron-2 (integral trap) with the K_p - -indices and the orientation of the axis of the geomagnetic dipole (φ).

a — K_p- indices ; б — geocentrical distances over which fluxes were measured on night portions of orbits ; в — same as б, but on morning portions of orbits ; г — orientation of the dipole axis (φ); XZ — — meridional plane of the solar-ecliptical system of coordinates ; SN — projection of the axis of the geomagnetic dipole on that surface; д — time intervals corresponding to the presence of information.

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* infrapaginal note from the preceding page.

* The values of φ are computed for the moments of time when the AES was situated at geocentrical distances corresponding to the horizontal line of Fig. 10, в (R ~ 5.7 R_E is approximately the middle part of the morning region of fluxes' registration of soft electrons over the initial portion of AES's flight trajectory.

Sun, that is, when the conditions for the penetration of the thermalized solar plasma through the southern neutral point were most favorable (provided obviously, such a penetration takes place).

The same periodicity in the appearance of fluxes is observed also on the night side, but with a shift in time; this periodicity is at the same time expressed more sharply than on the morning side where the number of registrations and the intensity of fluxes are lesser than on the night side. Separate exceptions correspond to days with increased state of geomagnetic disturbance.

It should be stressed that the data presented are preliminary, in particular because they are based upon observations, whose statistics are limited; subsequently a joint analysis of all the results of observations of fluxes of soft electrons will be required (including the observations conducted simultaneously with the aid of an electrostatic analyzer [19]).

Note that the data brought out, which show the presence of relationships between the cases of registration of soft electron fluxes on Electron-2 and the orientation of the axis of the geomagnetic dipole may have a great value, in particular, for the clarification of the character of solar plasma penetration into the Earth's magnetosphere and the filling of the geomagnetic trap. Note in connection with this that, for example in [50], there was already noted a possible link of certain daily and seasonal variations of the geomagnetic activity with the variations in the orientation of the axis of the geomagnetic dipole relative to the direction at the Sun.

7. - BRIEF REMARKS CONCERNING THE ORIGIN OF SOFT ELECTRONS BEYOND THE BOUNDARIES OF RADIATION BELTS

The daytime region of the zone of charged particles is separated from the unperturbed solar wind by a shock wave front, having formed at solar plasma incident supersonic flow onto the geomagnetic field (solar wind). In this zone the electrons have energies of the order of hundreds of ev and kev (up to 10 – 40 kev), whereas the electrons of the solar wind have an energy of the order of 10 ev. Apparently, pump-over of energy from protons of solar wind, having energies of hundreds of ev and kev, to electrons takes place near the boundary of the magnetosphere. Applied to the outermost belt this assumption has already been expressed in 1960 [2]. Shown as one of the possible mechanisms of such an acceleration of electrons of solar plasma was that of electron acceleration at motion of plasmoids in a nonuniform magnetic field [3].

One of the other possible acceleration mechanisms of electrons is linked with the fact that solar wind protons, having energy by three orders greater than electrons, may penetrate correspondingly deeper into the geomagnetic field. At the same time spatial distribution of charges must take place, namely of those inducing the electric field, which, in its turn, "pulls" or "draws up" electrons to protons with acceleration corresponding them [4].

It should be borne in mind that Explorer-18 registered in a narrow layer, apparently at the very front of the shock wave, electrons with energies ~ 30 kev (threshold value of the applied counters) [18]. Their intensity was estimated at $\sim 10^5 \text{cm}^{-2} \text{sec}^{-1}$. Apparently, a sufficiently effective acceleration mechanism of electrons acts at the shock wave front itself. It is interesting, that as the satellite orbit drifts farther away from subsolar point, the generation region of energy electrons, concentrated at small angles λ_{3C} in a narrow layer near the outer boundary of the transitional zone, expands notably. It is quite in order to assume that electrons of lower energies may have formed in the course of the acceleration process.

Certain possible acceleration mechanisms of electrons in the transitional region have been considered in the works [5, 51].

The question of origin of fluxes on the night side is more complex. This, in particular, is linked with the fact that the outer boundary of the zone of trapped radiation is situated in this case in the depth of the magnetosphere, as is shown by measurements, and is not contiguous to solar plasma fluxes. It is possible that the appearance of these fluxes on the night side is linked with plasma penetration through the neutral points of the magnetic field, as already mentioned [46]. For an open or strongly elongated magnetosphere the acceleration of particles in the magneto-neutral layer on account of instability in it, this layer being included between plane antiparallel magnetic fields, may also have a substantial significance [52 — 54].

We shall note in conclusion that the data brought out point to a great geophysical significance of the outermost zone of charged particles.

The close relationship of this zone with the structure of the peripheral regions of the geomagnetic field, and its orientation relative to the directions of solar plasma fluxes and of the interplanetary magnetic field, the link with the zones of maximum recurrences of aurorae (at least spatial), with solar and geomagnetic activities compel us to assume that the study of the outermost zone of charged particles may be the key to the understanding of mumerous, important and hitherto unresolved questions, such as, for example, the character of solar plasma penetration into the magnetosphere of the Earth and the filling of the geomagnetic trap.

However, one should bear in mind that the number of measurements of soft electron and proton fluxes still is totally insufficient and that their energy spectrum is not quite ascertained as yet. That is why one of the important problems of future space research is the further, careful study of fluxes of charged particles in the outermost zone, particularly at high latitudes, where the daytime and nighttime parts of this zone apparently join together near the neutral points of the geomagnetic field on the daytime side, and in the magneto-neutral layer in the night part of the zone. It is necessary to conduct these measurements on the same space probes and concomittantly with those of the magnitude and direction of the Earth's magnetic field, of energetic particle fluxes, and compare them with the data on solar and geomagnetic activities.

*** THE END ***

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ADDENDUM

ANNOTATION AT CORRECTION :

The authors of the above report took cognizance of the new publication with reference to fluxes of electrons with energies 10 kev beyond the zone of trapped radiation at low altitudes (to 2 700 km) conducted with the aid of the American satellite Injun-3 only after the end of the conference. (I. A. Fritz D. A. Gurnett.- J. Geophys. Res. 70, 2485, June 1, 1965). As pointed out by these authors, their results agree well with the results of observations completed at great heights on Soviet space probes Luna-2 [1, 6] and Mars-1 [15], and with the results obtained on Explorer-12 [14]. As was assumed, the indicated soft electrons penetrate into the zone of aurorae.

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